HELIUM-LEAK TESTING

Attachment 001

Standard Test Methods for Leaks Using the Mass Spectrometer Leak Detector in the Detector Probe Mode[1,2]

This standard is issued under the fixed designation E 499; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This specification has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover procedures for testing and locating the sources of gas leaking at the rate of 4.5×10^{-13} mol/s (1×10^{-8} Std cm ^{3}/s)[3] or greater. The test may be conducted on any device or component across which a pressure differential of helium or other suitable tracer gas may be created, and on which the effluent side of the leak to be tested is accessible for probing with the mass spectrometer sampling probe.

1.2 Two test methods are described:

1.2.1 *Test Method A*—Direct probing, and

1.2.2 *Test Method B*—Accumulation.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 1316 Terminology for Nondestructive Examinations[4]

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing[5]

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel[5]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, see Terminology E 1316, Section E.

4. Summary of Test Methods

4.1 Section 1.8 of the Leakage Testing Handbook[6] will be of value to some users in determining which leak test method to use.

4.2 These test methods require a leak detector with a full-scale readout of at least 4.5×10^{-12} mol/s (1×10^{-7} Std cm^3/s)[3] on the most sensitive range, a maximum 1-min drift of zero and sensitivity of ±5 % of full scale on this range, and ±2 % or less on others (see 7.1). The above sensitivities are those obtained by probing an actual standard leak in atmosphere with the detector, or sampling, probe, and *not* the sensitivity of the detector to a standard leak attached directly to the vacuum system.

4.3 *Test Method A, Direct Probing* (see Fig. 1), is the simplest test, and may be used in parts of any size, requiring only that a tracer gas pressure be created across the area to be tested, and the searching of the atmospheric side of the area be with the detector probe. This test method detects leakage and its source or sources. Experience has shown that leak testing down to 4.5×10^{-11} mol/s (1×10^{-6} Std cm ^{3}/s)[3] in factory environments will usually be satisfactory if reasonable precautions against releasing gas like the tracer gas in the test area are observed, and the effects of other interferences (Section 6) are considered.

4.4 *Test Method B, Accumulation Testing* (see Fig. 2), provides for the testing of parts up to several cubic metres in volume as in Fig. 2(a) or in portions of larger devices as in Fig. 2(b). This is accomplished by allowing the leakage to accumulate in the chamber for a fixed period, while keeping it well mixed with a fan, and then testing the internal atmosphere for an increase in tracer gas content with the detector probe. The practical sensitivity attainable with this method depends primarily on two things: first, on the volume between the chamber and the object; and second, on the amount of outgassing of tracer gas produced by the object. Thus, a part having considerable exposed rubber, plastic, blind cavities or threads cannot be tested with the sensitivity of a smooth metallic part. The time in which a leak can be detected is directly proportional to

[1] These test methods are under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and are the direct responsibility of Subcommittee E07.08 on Leak Testing.

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[2] (Atmospheric pressure external, pressure above atmospheric internal). This document covers the Detector Probe Mode described in Guide E 432.

[3] The gas temperature is referenced to 0°C. To convert to another gas reference temperature, T_{ref}, multiply the leak rate by $(T_{ref} + 273)/273$.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[6] Marr, J. William, "Leakage Testing Handbook," prepared for Liquid Propulsion Section, Jet Propulsion Laboratory, National Aeronautics and Space Administration, Pasadena, CA, Contract NAS 7-396, June 1961.

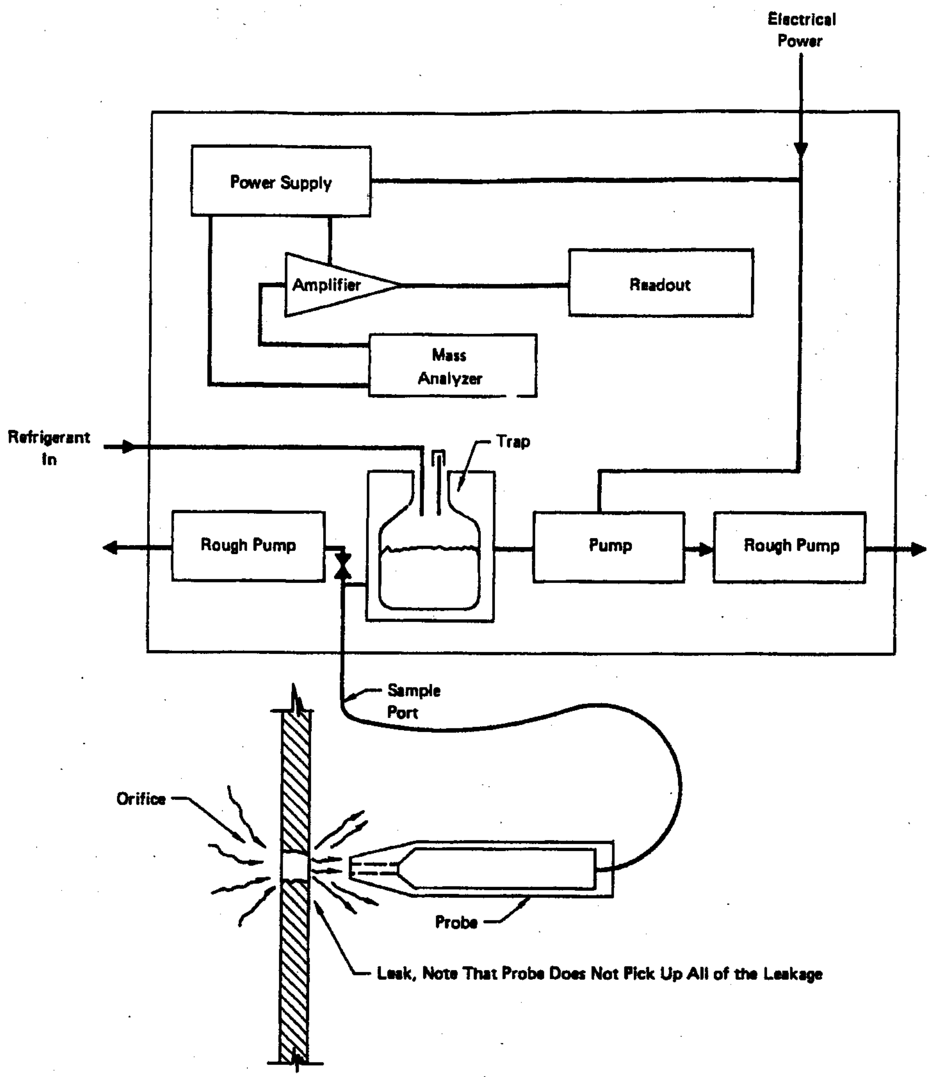


FIG. 1 Method A

the leak rate and inversely proportional to the volume between the chamber and the part. In theory, extremely small leaks can be detected by this test method; however, the time required and the effects of other interferences limit the practical sensitivity of this test method to about 4.5×10^{-13} mol/s (1×10^{-8} Std cm^3/s)[3] for small parts.

5. Personnel Qualification

5.1 It is recommended that personnel performing leak testing attend a dedicated training course on the subject and pass a written examination. The training course should be appropriate for NDT level II qualification according to Recommended Practice No. SNT-TC-1A of the American Society for Nondestructive Testing or ANSI/ASNT Standard CP-189.

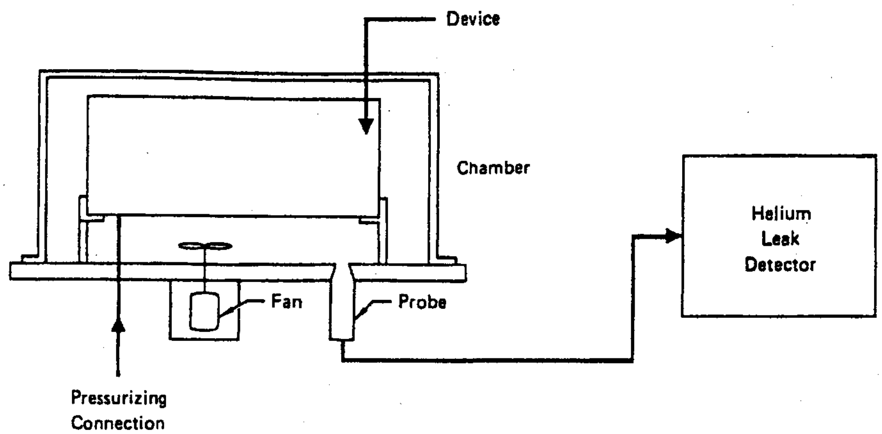
6. Significance and Use

6.1 Test Method A is frequently used to test large systems and complex piping installations that can be filled with a trace gas. Helium is normally used. The test method is used to locate leaks but cannot be used to quantify except for approximation. Care must be taken to provide sufficient ventilation to prevent increasing the helium background at the test site. Results are limited by the helium background and the percentage of the leaking trace gas captured by the probe.

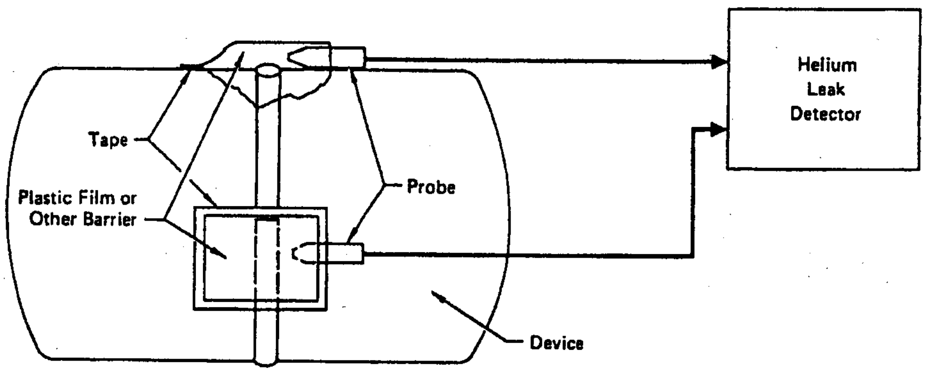
6.2 Test Method B is used to increase the concentration of trace gas coming through the leak by capturing it within an enclosure until the signal above the helium background can be detected. By introducing a calibrated leak into the same volume for a recorded time interval, leak rates can be measured.

7. Interferences

7.1 *Atmospheric Helium*—The atmosphere contains about five parts per million (ppm) of helium, which is being continuously drawn in by the detector probe. This background must be "zeroed out" before leak testing using helium can proceed. Successful leak testing is contingent on the ability of the detector to discriminate between normal atmospheric



a) Accumulation Leak Test, Complete Device in Chamber



b) Accumulation Leak Test, Flexible Shroud over a Small Portion of Device

FIG. 2 Method B

helium, which is very constant, and an increase in helium due to a leak. If the normally stable atmospheric helium level is increased by release of helium in the test area, the reference level becomes unstable, and leak testing more difficult.

7.2 *Helium Outgassed from Absorbent Materials*—Helium absorbed in various nonmetallic materials (such as rubber or plastics) may be released during the test. If the rate and magnitude of the amount released approaches the amount released from the leak, the reliability of the test is decreased. The amount of such materials or their exposure to helium must then be reduced to obtain a meaningful test.

7.3 *Pressurizing with Test Gas*—In order to evaluate leakage accurately, the test gas in all parts of the device must contain substantially the same amount of tracer gas. When the device contains air prior to the introduction of test gas, or when an inert gas and a tracer gas are added separately, this may not be true. Devices in which the effective diameter and length are not greatly different (such as tanks) may be tested satisfactorily by simply adding tracer gas. However, when long or restricted systems are to be tested, more uniform tracer distribution will be obtained by first evacuating to less than 100 Pa (a few torr), and then filling with the test gas. The latter must be premixed if not 100 % tracer.

7.4 *Dirt and Liquids*—As the orifice in the detector probe is very small, the parts being tested should be clean and dry to avoid plugging. Reference should be frequently made to a standard leak to ascertain that this has not happened.

8. Apparatus

8.1 *Helium Leak Detector*, equipped with atmospheric detector probe. To perform tests as specified in this standard, the detector should be adjusted for testing with helium and should have the following minimum features:

8.1.1 *Sensor Mass Analyzer*.

8.1.2 *Readout*, analog or digital.

8.1.3 *Range (linear)*—A signal equivalent to 4.5×10^{-11} mol/s (1×10^{-6} Std cm^3/s)[3] or larger must be detectable.

8.1.4 *Response time*, 3 s or less.

8.1.5 *Stability of Zero and Sensitivity*— A maximum variation of ±5 % of full scale on the most sensitive range while the probe is active; a maximum variation of ±2 % of full scale on other ranges for a period of 1 min.

NOTE 1—Variations may be a function of environmental interferences rather than equipment limitations.

8.1.6 *Controls*:

8.1.6.1 *Range*, prefereable in scale steps of 3× and 10×.

8.1.6.2 *Zero*, having sufficient range to null out atmospheric helium. Automatic null to zero is preferred.

8.2 *Helium Leak Standard*—To perform leak tests as specified in this standard, the leak standard should meet the following minimum requirements:

8.2.1 *Ranges*—4.5×10^{-8} to 4.5×10^{-13} mol/s (10^{-3} to 10^{-8} Std cm^3/s)[3] full scale calibrated for discharge to atmosphere.

8.2.2 *Adjustability*—Adjustable leak standards are a convenience but are not mandatory.

8.2.3 *Accuracy*, ±25 % of full-scale value or better.

8.2.4 *Temperature Coefficient*, shall be stated by manufacturer.

8.3 *Helium Leak Standard*, as in 8.2 but with ranges of 4.5×10^{-12} or 4.5×10^{-13} mol/s (10^{-7} or 10^{-8} Std cm^3/s).[3]

8.4 *Other Apparatus*—Fixtures or other equipment specific to one test method are listed under that test method.

9. Material

9.1 *Test Gas Requirements*:

9.1.1 To be satisfactory, the test gas shall be nontoxic, nonflammable, not detrimental to common materials, and inexpensive. Helium, or helium mixed with air, nitrogen, or some other suitable inert gas meets the requirements. If the test specification allows leakage of 4.5×10^{-10} mol/s (1×10^{-5} Std cm ^{3}/s)[3] or more, or if large vessels are to be tested, consideration should be given to diluting the tracer gas with another gas such as dry air or nitrogen. This will avoid excessive helium input to the sensor and in the case of large vessels, save tracer gas expense (Note 2).

9.1.2 *Producing Premixed Test Gas*—If the volume of the device or the quantity to be tested is small, premixed gases can be conveniently obtained in cylinders. The user can also mix gases by batch in the same way. Continuous mixing using calibrated orifices is another simple and convenient method when the test pressure does not exceed 50 % of the tracer gas pressure available.

NOTE 2—When a vessel is not evacuated prior to adding test gas, the latter is automatically diluted by one atmosphere of air.

9.2 *Liquid Nitrogen*, or other means of cold trap refrigeration as specified by the maker of the leak detector.

10. Calibration

10.1 The leak detectors used in making leak tests by these test methods are not calibrated in the sense that they are taken to the standards laboratory, calibrated, and then returned to the job. Rather, the leak detector is used as a comparator between a leak standard (8.2) (set to the specified leak size) which is part of the instrumentation, and the unknown leak. However, the sensitivity of the leak detector is checked and adjusted on the job so that a leak of specified size will give a readily observable, but not off-scale reading. More specific details are given in Section 11 under the test method being used. To verify sensitivity, reference to the leak standard should be made before and after a prolonged test. When rapid repetitive testing of many items is required, refer to the leak standard often enough to ensure that desired test sensitivity is maintained.

11. Procedure

11.1 *General Considerations*:

11.1.1 *Test Specifications*—A testing specification shall be in hand. This shall include:

11.1.1.1 The gas pressure on the high side of the device to be tested; also on the low side if it need differ from atmospheric pressure.

11.1.1.2 The test gas composition, if there is need to specify it.

11.1.1.3 The maximum allowable leak rate in standard cubic centimetres per second.

11.1.1.4 Whether the leak rate is for each leak or for total leakage of the device.

11.1.1.5 If an "each leak" specification, whether or not other than seams, joints, and fittings needs to be tested.

11.1.2 *Safety Factor*—Where feasible, it should be ascertained that a reasonable safety factor has been allowed between the actual operational requirements of the device and the maximum specified for testing. Experience indicates that a factor of at least 10 should be used when possible. For example, if a maximum total leak rate for satisfactory operation of a device is 2.2×10^{-10} mol/s (5×10^{-6} Std cm^3/s)[3], the test requirement should be 2.2×10^{-11} mol/s (5×10^{-7} Std cm ^{3}/s)[3] or less.

11.1.3 *Test Pressure*—The device should be tested at or above its operating pressure and with the pressure drop in the normal direction, where practical. Precautions should be taken so that the device will not fail during pressurization, or that the operator is protected from the consequences of a failure.

11.1.4 *Disposition or Recovery of Test Gas*—Test gas should never be dumped into the test area if further testing is planned. It should be vented outdoors or recovered for reuse if the volume to be used makes this worthwhile.

11.1.5 *Detrimental Effects of Helium Tracer Gas*—This gas is quite inert, and seldom causes any problems with most materials, particularly when used in gaseous form for leak testing and then removed. When there is a question as to the compatibility of the tracer with a particular material, an authority on the latter should be consulted. This is particularly true when helium is sealed in contact with glass or other barriers that it may permeate.

11.1.6 *Correlation of Test Gas Leakage with Other Gases or Liquids at Different Operating Pressures*:

11.1.6.1 Given the normal variation in leak geometry, accurate correlation is an impossibility. However, if a safety factor of ten or more is allowed, in accordance with 11.1.2, adequate correlation for gas leakage within these limits can usually be obtained by assuming viscous flow and using the equation:

$$Q_2 = (Q_1 N_1/N_2)[(P_2{}^2 - P_1{}^2)/(P_4{}^2 - P_3{}^2)]$$

where:

Q_2 = test leakage, Pa·m^3/s (standard cm^3/s),
Q_1 = operational leakage, Pa·m^3/s (standard cm^3/s),
N_2 = viscosity of test gas (Note 3),
N_1 = viscosity of operational gas (Note 3),
P_2, P_1 = absolute pressures on high and low sides at test, and
P_4, P_3 = absolute pressures on high and low sides in operation (Note 4).

11.1.6.2 Experience has shown that, at the same pressures, gas leaks smaller than 4.5×10^{-10} mol/s (1×10^{-5} Std cm^3/s)[3] will not show visible leakage of a liquid, such as water, which evaporates fairly rapidly. For slowly evaporating liquids such as lubricating oil, the gas leakage should be another order of magnitude smaller, 4.5×10^{-11} mol/s (1×10^{-6} Std cm^3/s).[3] See Santeler and Moller[7] for further discussion of this topic.

NOTE 3—Viscosity differences between gases are a relatively minor effect and can be ignored if desired.

NOTE 4—It will be observed from this equation that the leakage increases at a rate considerably greater than that of the pressure increase. For this reason it is often desirable to increase the sensitivity of the test by testing at the maximum safe pressure for the part. Increased sensitivity may even be obtained with the same amount of helium by increasing the pressure with another less expensive gas, such as air.

11.2 *Test Method A* (refer to 4.3 and Fig. 1):

11.2.1 *Apparatus*:

11.2.1.1 *Test Specification.*

11.2.1.2 *Helium Leak Detector*, with atmospheric detector, sampling probe.

11.2.1.3 *Helium Leak Standard*, discharge to atmosphere. Size equal to helium content of maximum leak rate per specification.

11.2.1.4 *Helium Leak Standard*, discharge to vacuum. Size: anywhere between 4.5×10^{-11} mol/s (1×10^{-6} Std cm^3/s)[3] and 4.5×10^{-13} mol/s (1×10^{-9} Std cm^3/s),[3] unless otherwise specified by maker of leak detector.

11.2.1.5 *Test Gas*, at or above specification pressure.

11.2.1.6 *Pressure Gages, Valves, and Piping*, for introducing test gas, and if required, vacuum pump for evacuating device.

11.2.1.7 *Liquid Nitrogen*, if required.

11.2.2 *Procedure*:

11.2.2.1 Set helium leak standard at maximum helium content of specification leakage. Example:
Max leak rate: 4.5×10^{-9} mol/s (1×10^{-4} Std cm^3/s).[3] Test gas: 1 % helium in air. Set standard at 4.5×10^{-9} mol/s (1×10^{-4} Std cm^3/s)[3] $\times 0.01 = 4.5 \times 10^{-11}$ mol/s (1×10^{-6} Std cm^3/s).[3]

11.2.2.2 Start detector, warm up, fill trap with liquid nitrogen if required, and adjust in accordance with manufacturer's instructions, using leak standard 11.2.1.4 attached to vacuum system.

11.2.2.3 Attach atmospheric detector probe to detector sample port in place of leak standard and open valve of detector probe, if adjustable type is being used, to maximum leak rate under which detector will operate properly.

11.2.2.4 Rezero detector to compensate for atmospheric helium.

11.2.2.5 With orifice of leak standard (11.2.1.3) in a horizontal position, hold the tip of the detector probe directly in line with and 1.5 ± 0.5 mm (0.06 ± 0.02 in.) away from the end of the orifice, and observe reading (Note 5).

11.2.2.6 Remove probe from standard leak and note minimum and maximum readings due to atmospheric helium variations or other instabilities.

11.2.2.7 If 11.2.2.6 is larger than 30 % of 11.2.2.5, take steps to reduce the helium added to the atmosphere, or to eliminate other causes of instability. If this cannot be done, testing at this level of sensitivity may not be practical.

11.2.2.8 Evacuate (if required) and apply test gas to device at specified pressure.

11.2.2.9 *Probe Areas Suspected of Leaking*— Probe shall be held on or not more than 1 mm (0.04 in.) from the surface of the device, and moved not faster than 20 mm/s (0.8 in./s). If leaks are located which cause a "reject" indication they must be repaired before making final acceptance test.

11.2.2.10 Maintain an orderly procedure in probing the required areas, preferably identifying them as tested, and plainly indicating points of leakage.

11.2.2.11 At completion of the test evacuate or purge test gas from the device, if required.

11.2.2.12 Write a test report or otherwise indicate test results as required.

NOTE 5—If necessary to obtain a reasonable instrument deflection, adjust range, rezero if necessary, and reapply sampling probe to leak standard.

11.3 *Test Method B* (refer to 4.4 and Fig. 2):

11.3.1 *Apparatus*—Same as for Test Method A, except that equipment for enclosing all or part of the item to be tested is required as shown in Fig. 2.

11.3.2 *Procedure*:

11.3.2.1 *Set-up*—Same as 11.2.2.1-11.2.2.7, Test Method A, except that somewhat larger variations in atmospheric helium can be tolerated due to the isolation of the part during test.

11.3.2.2 *Sensitivity Setting*—In general, it will be advantageous to use the maximum stable sensitivity setting on the leak detector, in order to reduce the accumulation time to a minimum.

11.3.2.3 Insert the part to be tested (unpressurized), the leak standard (11.2.1.3), and the detector probe in the Fig. 2 enclosure.

11.3.2.4 Note the rate of increase of detector indication.

11.3.2.5 Remove the leak standard, pressurize the part with test gas, and again note rate of rise, if any. If 11.3.2.5 exceeds 11.3.2.4, reject part.

11.3.2.6 Remove the part from the enclosure and purge out any accumulated helium.

11.3.2.7 Evacuate or purge test gas from the part, if required.

11.3.2.8 Write a test report or otherwise indicate test results as required.

12. Precision and Bias

12.1 *Precision*

12.1.1 *Test Method A*—No statement on precision is made.

12.1.2 *Test Method B*—Replicate tests by the same operator with the same equipment should not be considered suspect if the results agree within ±25 %. Replicate tests from a second facility should not be considered suspect if the results agree within± 50 %.

12.2 *Bias*:

12.2.1 *Test Method A*—Due to the nature of the test no statement of bias is possible. Calibration standards are used

[7] Santeler, D. J., and Moller, T. W., "Fluid Flow Conversion in Leaks and Capillaries," *Vacuum Symposium Transactions*, Pergamon Press, London, 1956, p 29. Also General Electric Company Report R56GL261.

only to ensure that the leak detector is functioning properly. No leak measurement is intended.

12.2.2 *Test Method B*—Bias of leak rates between 10^{-7} and 10^{-4} Pa·m^3/s (10^{-6} to 10^{-3} standard cm ^{3}/s) are typically ±25 %.

13. Keywords

13.1 bell jar leak test; bomb mass spectrometer leak test; helium leak test; helium leak testing; leak testing; mass spectrometer leak testing; sealed object mass spectrometer leak test

UN POP TESTS

Attachment 002

each test sample, there is no leakage of liquid from the package.

[Amdt. 178-97, 55 FR 52723, Dec. 21, 1990, as amended at 56 FR 66286, Dec. 20, 1991; Amdt. 178-99, 58 FR 51534, Oct. 1, 1993; Amdt. 178-102, 59 FR 28494, June 2, 1994; 65 FR 50462, Aug. 18, 2000]

§ 178.606 Stacking test.

(a) *General.* All packaging design types other than bags must be subjected to a stacking test.

(b) *Number of test samples.* Three test samples are required for each different packaging. For periodic retesting of packagings constructed of stainless steel, monel, or nickel, only one test sample is required. Exceptions for the number of aluminum and steel sample packagings used in conducting the stacking test are subject to the approval of the Associate Administrator for Hazardous Materials Safety. Notwithstanding the provisions of § 178.602(a) of this subpart, combination packagings may be subjected to the stacking test without their inner packagings, except where this would invalidate the results of the test.

(c) *Test method*—(1) *Design qualification testing.* The test sample must be subjected to a force applied to the top surface of the test sample equivalent to the total weight of identical packages which might be stacked on it during transport; where the contents of the test sample are non-hazardous liquids with specific gravities different from that of the liquid to be transported, the force must be calculated based on the specific gravity that will be marked on the packaging. The minimum height of the stack, including the test sample, must be 3.0 m (10 feet). The duration of the test must be 24 hours, except that plastic drums, jerricans, and composite packagings 6HH intended for liquids shall be subjected to the stacking test for a period of 28 days at a temperature of not less than 40°C (104°F). Alternative test methods which yield equivalent results may be used if approved by the Associate Administrator for Hazardous Materials Safety. In guided load tests, stacking stability must be assessed after completion of the test by placing two filled packagings of the same type on the test sample. The stacked packages must maintain their position for one hour. Plastic packagings must be cooled to ambient temperature before this stacking stability assessment.

(2) *Periodic retesting.* The test sample must be tested in accordance with:

(i) Section 178.606(c)(1) of this subpart; or

(ii) The packaging may be tested using a dynamic compression testing machine. The test must be conducted at room temperature on an empty, unsealed packaging. The test sample must be centered on the bottom platen of the testing machine. The top platen must be lowered until it comes in contact with the test sample. Compression must be applied end to end. The speed of the compression tester must be one-half inch plus or minus one-fourth inch per minute. An initial preload of 50 pounds must be applied to ensure a definite contact between the test sample and the platens. The distance between the platens at this time must be recorded as zero deformation. The force A to then be applied must be calculated using the formula:

Liquids: $A = (n - 1) [w + (s \times v \times 8.3 \times .98)] \times 1.5;$

Solids: $A = (n - 1) [w + (s \times v \times 8.3 \times .95)] \times 1.5$

Where:

A = applied load in pounds.
n = minimum number of containers that, when stacked, reach a height of 3 m.
s = specific gravity of lading.
w = maximum weight of one empty container in pounds.
v = actual capacity of container (rated capacity + outage) in gallons.

And:

8.3 corresponds to the weight in pounds of 1.0 gallon of water.
1.5 is a compensation factor that converts the static load of the stacking test into a load suitable for dynamic compression testing.

(d) *Criteria for passing the test.* No test sample may leak. In composite packagings or combination packagings, there must be no leakage of the filling substance from the inner receptacle, or inner packaging. No test sample may show any deterioration which could adversely affect transportation safety or any distortion likely to reduce its strength, cause instability in stacks of packages, or cause damage to inner packagings likely to reduce safety in transportation. For the dynamic compression test, a container passes the test if, after application of the required load, there is no buckling of the sidewalls sufficient to cause damage to its expected contents; in no case may the maximum deflection exceed one inch.

[Amdt. 178–97, 55 FR 52723, Dec. 21, 1990, as amended at 56 FR 66286, Dec. 20, 1991; 57 FR 45465, Oct. 1, 1992; Amdt. 178–102, 59 FR 28494, June 2, 1994; Amdt. 178–106, 59 FR 67522, Dec. 29, 1994; 65 FR 58632, Sept. 29, 2000]

§ 178.607 Cooperage test for bung-type wooden barrels.

(a) *Number of samples.* One barrel is required for each different packaging.

(b) *Method of testing.* Remove all hoops above the bilge of an empty barrel at least two days old.

(c) *Criteria for passing the test.* A packaging passes the cooperage test only if the diameter of the cross-section of the upper part of the barrel does not increase by more than 10 percent.

§ 178.608 Vibration standard.

(a) Each packaging must be capable of withstanding, without rupture or leakage, the vibration test procedure outlined in this section.

(b) Test method. (1) Three sample packagings, selected at random, must be filled and closed as for shipment.

(2) The three samples must be placed on a vibrating platform that has a vertical or rotary double-amplitude (peak-to-peak displacement) of one inch. The packages should be constrained horizontally to prevent them from falling off the platform, but must be left free to move vertically, bounce and rotate.

(3) The test must be performed for one hour at a frequency that causes the package to be raised from the vibrating platform to such a degree that a piece of material of approximately 1.6 mm (0.063 inch) thickness (such as steel strapping or paperboard) can be passed between the bottom of any package and the platform.

(4) Immediately following the period of vibration, each package must be removed from the platform, turned on its side and observed for any evidence of leakage.

(5) Other methods, at least equally effective, may be used, if approved by the Associate Administrator for Hazardous Materials Safety.

(c) *Criteria for passing the test.* A packaging passes the vibration test if there is no rupture or leakage from any of the packages. No test sample should show any deterioration which could adversely affect transportation safety or any distortion liable to reduce packaging strength.

[Amdt. 178–97, 55 FR 52723, Dec. 21, 1990, as amended at 56 FR 66286, Dec. 20, 1991]

§ 178.609 Test requirements for packagings for infectious substances (etiologic agents).

(a) Samples of each packaging must be prepared for testing as described in paragraph (b) of this section and then subjected to the tests in paragraphs (d) through (i) of this section.

(b) Samples of each packaging must be prepared as for transport except that a liquid or solid infectious substance should be replaced by water or, where conditioning at −18 °C (0 °F) is specified, by water/antifreeze. Each primary receptacle must be filled to 98 percent capacity. Packagings for live animals should be tested with the live animal being replaced by an appropriate dummy of similar mass.

(c) Packagings prepared as for transport must be subjected to the tests in table I of this paragraph, which, for test purposes, categorizes packagings according to their material characteristics. For outer packagings, the headings in table I relate to fiberboard or similar materials whose performance may be rapidly affected by moisture; plastics, other than expanded plastics or film, which may embrittle at low temperature; and other materials such as metal whose performance is not significantly affected by moisture or temperature. Inner packagings may be of plastics, other than expanded plastics or film. Where a primary receptacle and a secondary packaging of an inner packaging are made of different materials, the material of the primary receptacle determines the appropriate test.

(d) Paper or fiberboard packagings must be conditioned for at least 24 hours immediately prior to testing in an atmosphere maintained—

(1) At 50 percent ±2 percent relative humidity, and at a temperature of 23 °C±2 °C (73 °F±4 °F). Average values should fall within these limits. Short-term fluctuations and measurement limitations may cause individual measurements to vary by up to ± 5 percent relative humidity without significant impairment of test reproducibility;

(2) At 65 percent ±2 percent relative humidity, and at a temperature of 20 °C±2 °C (68 °F±4 °F), or 27 °C±2 °C (81 °F±4 °F). Average values should fall within these limits. Short-term fluctuations and measurement limitations may cause individual measurements to vary by up to ± 5 percent relative humidity without significant impairment of test reproducibility; or

(3) For testing at periodic intervals only (i.e., other than initial design qualification testing), at ambient conditions.

(e) Except as otherwise provided, each packaging must be closed in preparation for testing in the same manner as if prepared for actual shipment. All closures must be installed using proper techniques and torques.

(f) Bung-type barrels made of natural wood must be left filled with water for at least 24 hours before the tests.

[Amdt. 178–97, 55 FR 52728, Dec. 21, 1990, as amended at 56 FR 66286, Dec. 20, 1991; Amdt. 178–106, 59 FR 67522, Dec. 29, 1994]

§ 178.603 Drop test.

(a) *General.* The drop test must be conducted for the qualification of all packaging design types and performed periodically as specified in § 178.601(e). For other than flat drops, the center of gravity of the test packaging must be vertically over the point of impact. Where more than one orientation is possible for a given drop test, the orientation most likely to result in failure of the packaging must be used. The number of drops required and the packages' orientations are as follows:

Packaging	No. of tests (samples)	Drop orientation of samples
Steel drums, Aluminum drums, Metal drums (other than steel or aluminum), Steel Jerricans, Plywood drums, Wooden barrels, Fiber drums, Plastic drums and Jerricans, Composite packagings which are in the shape of a drum.	Six—(three for each drop).	First drop (using three samples): The package must strike the target diagonally on the chime or, if the packaging has no chime, on a circumferential seam or an edge. Second drop (using the other three samples): The package must strike the target on the weakest part not tested by the first drop, for example a closure or, for some 7 cylindrical drums, the welded longitudinal seam of the drum body.
Boxes of natural wood, Plywood boxes, Reconstituted wood boxes, Fiberboard boxes, Plastic boxes, Steel or aluminum boxes, Composite packagings which are in the shape of a box.	Five—(one for each drop).	First drop: Flat on the bottom (using the first sample). Second drop: Flat on the top (using the second sample). Third drop: Flat on the long side (using the third sample). Fourth drop: Flat on the short side (using the fourth sample). Fifth drop: On a corner (using the fifth sample).
Bags—single-ply with a side seam	Three—(three drops per bag).	First drop: Flat on a wide face (using all three samples). Second drop: Flat on a narrow face (using all three samples). Third drop: On an end of the bag (using all three samples).
Bags—single-ply without a side seam, or multi-ply.	Three—(two drops per bag).	First drop: Flat on a wide face (using all three samples). Second drop: On an end of the bag (using all three samples).

(b) *Exceptions.* For testing of single or composite packagings constructed of stainless steel, nickel, or monel at periodic intervals only (i.e., other than design qualification testing), the drop test may be conducted with two samples, one sample each for the two drop orientations. These samples may have been previously used for the hydrostatic pressure or stacking test. Exceptions for the number of steel and aluminum packaging samples used for conducting the drop test are subject to the approval of the Associate Administrator for Hazardous Materials Safety.

(c) *Special preparation of test samples for the drop test.* Testing of plastic drums, plastic jerricans, plastic boxes other than expanded polystyrene boxes, composite packagings (plastic material), and combination packagings with plastic inner packagings other than plastic bags intended to contain solids or articles must be carried out when the temperature of the test sample and its contents has been reduced to −18 °C

(0 °F) or lower. Test liquids shall be kept in the liquid state, if necessary, by the addition of anti-freeze. Test samples prepared in this way are not required to be conditioned in accordance with §178.602(d).

(d) *Target*. The target must be a rigid, non-resilient, flat and horizontal surface.

(e) *Drop height*. Drop heights, measured as the vertical distance from the target to the lowest point on the package, must be determined as follows:

(1) For solids and liquids, if the test is performed with the solid or liquid to be transported or with a non-hazardous material having essentially the same physical characteristic, the drop height must be determined according to packing group, as follows:

(i) Packing Group I: 1.8 m (5.9 feet).

(ii) Packing Group II: 1.2 m (3.9 feet).

(iii) Packing Group III: 0.8 m (2.6 feet).

(2) For liquids, if the test is performed with water—

(i) Where the materials to be carried have a specific gravity not exceeding 1.2, drop height must be determined according to packing group, as follows:

(A) Packing Group I: 1.8 m (5.9 feet).

(B) Packing Group II: 1.2 m (3.9 feet).

(C) Packing Group III: 0.8 m (2.6 feet).

(ii) Where the materials to be transported have a specific gravity exceeding 1.2, the drop height must be calculated on the basis of the specific gravity (SG) of the material to be carried, rounded up to the first decimal, as follows:

(A) Packing Group I: SG × 1.5 m (4.9 feet).

(B) Packing Group II: SG × 1.0 m (3.3 feet).

(C) Packing Group III: SG × 0.67 m (2.2 feet).

(f) *Criteria for passing the test*. A package is considered to successfully pass the drop tests if for each sample tested—

(1) For packagings containing liquid, each packaging does not leak when equilibrium has been reached between the internal and external pressures, except for inner packagings of combination packagings when it is not necessary that the pressures be equalized;

(2) For removable head drums for solids, the entire contents are retained by an inner packaging (e.g., a plastic bag) even if the closure on the top head of the drum is no longer sift-proof;

(3) For a bag, neither the outermost ply nor an outer packaging exhibits any damage likely to adversely affect safety during transport;

(4) For a composite or combination packaging, there is no damage to the outer packaging likely to adversely affect safety during transport, and there is no leakage of the filling substance from the inner packaging;

(5) Any discharge from a closure is slight and ceases immediately after impact with no further leakage; and

(6) No rupture is permitted in packagings for materials in Class 1 which would permit spillage of loose explosive substances or articles from the outer packaging.

[Amdt. 178-97, 55 FR 52723, Dec. 21, 1990, as amended at 56 FR 66286, Dec. 20, 1991; 57 FR 45465, Oct. 1, 1992; Amdt. 178-99, 58 FR 51534, Oct. 1, 1993; Amdt. 178-106, 59 FR 67522, Dec. 29, 1994; 65 FR 50462, Aug. 18, 2000]

§178.604 Leakproofness test.

(a) *General*. The leakproofness test must be performed with compressed air or other suitable gases on all packagings intended to contain liquids, except that:

(1) The inner receptacle of a composite packaging may be tested without the outer packaging provided the test results are not affected; and

(2) This test is not required for inner packagings of combination packagings.

(b) *Number of packagings to be tested*—(1) *Production testing*. All packagings subject to the provisions of this section must be tested and must pass the leakproofness test:

(i) Before they are first used in transportation; and

(ii) Prior to reuse, when authorized for reuse by §173.28 of this subchapter.

(2) *Design qualification and periodic testing*. Three samples of each different packaging must be tested and must pass the leakproofness test. Exceptions for the number of samples used in conducting the leakproofness test are subject to the approval of the Associate Administrator for Hazardous Materials Safety.

(c) *Special preparation*—(1) For design qualification and periodic testing,

TRANSPORTABILITY TESTS

Attachment 003

4.2. Test Method No. 2 - Hazard Course. This step provides for the specimen load to be driven over a 200-foot-long segment of concrete-paved road which consists of two series of railroad ties projecting 6 inches above the level of the road surface. This hazard course was traversed two times (see figure 2).

a. The first series of ties are spaced on 8-foot centers and alternately positioned on opposite sides of the road centerline for a distance of 50 feet.

b. Following the first series of ties, a paved roadway of 75 feet separates the first and second series of railroad ties.

c. The second series of ties is alternately positioned similarly to the first, but spaced on 10-foot centers for a distance of 50 feet.

d. The test load is driven across the hazard course at speeds that would produce the most violent vertical and side-to-side rolling reaction obtainable in traversing the hazard course (approximately 5 mph).

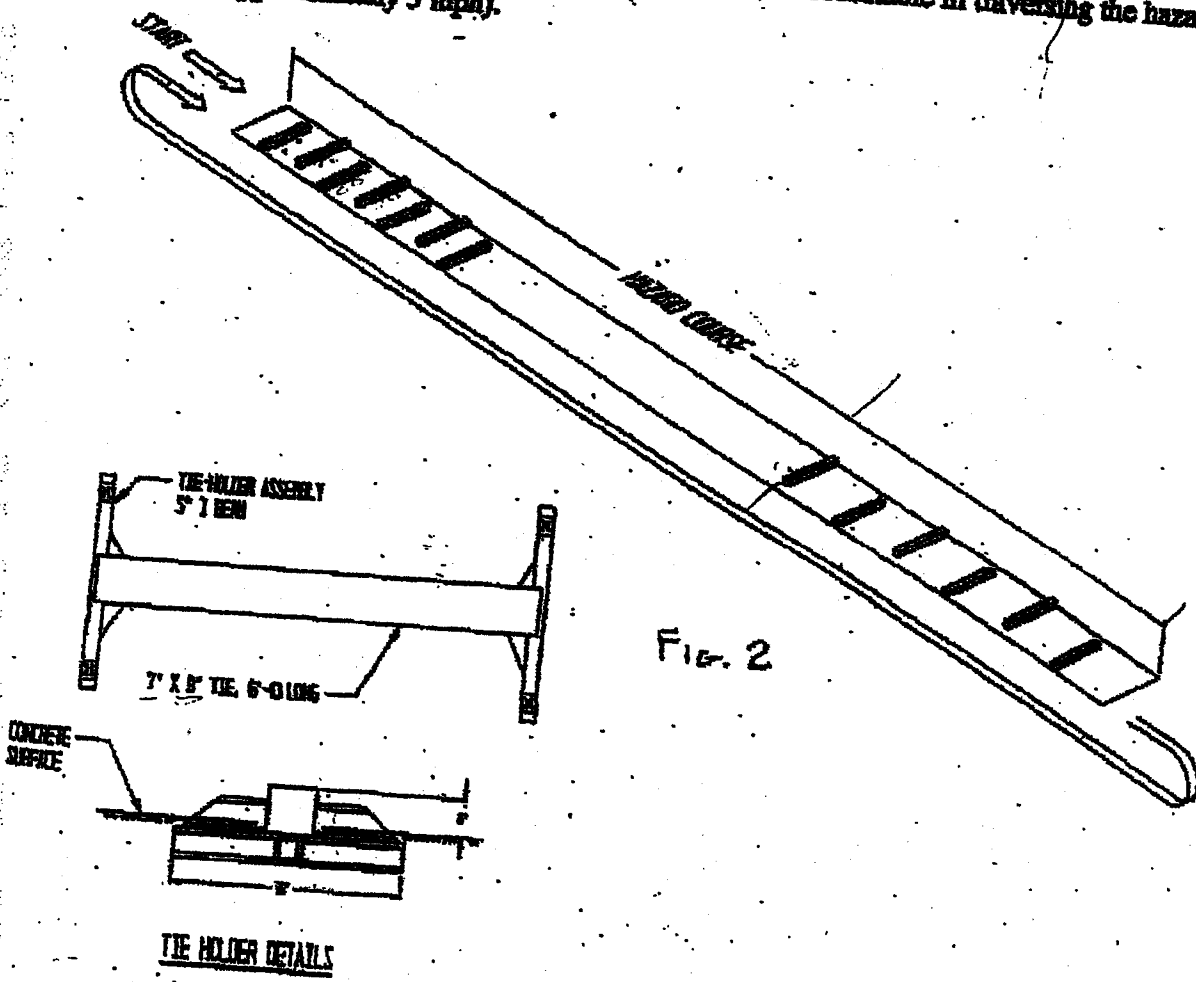


Fig. 2

4.3. Test Method No. 3 - Road Trip. Using a suitable truck/tractor and trailer, or tactical vehicle, the tactical vehicle/specimen load of test methods nos. 1 and 2 shall be driven/towed for a total distance of at least 30 miles over a combination of roads surfaced with gravel, concrete, or asphalt. Test route shall include curves, corners, railroad crossings, cattle guards, and stops and starts. The test vehicle shall travel at the maximum speed suitable for the particular road being traversed, except as limited by legal restrictions. This step provides for the tactical vehicle/specimen load to be subjected to three full airbrake stops while traveling in the forward direction and one in the reverse direction while traveling down a 7 degree grade. The first three stops are at 5, 10, and 15 mph, while the stop in the reverse direction is of approximately 5 mph.

4.6. Test Method No. 6 - Washboard Course. Using a suitable truck/ tractor, and/or tactical vehicle, the specimen shall be towed/driven over the washboard course (figure 4) at a speed which produces the most violent response in the particular test load (as indicated by the resonant frequency of the suspension system beneath the load). The washboard course shall be constructed as shown in figure 4.

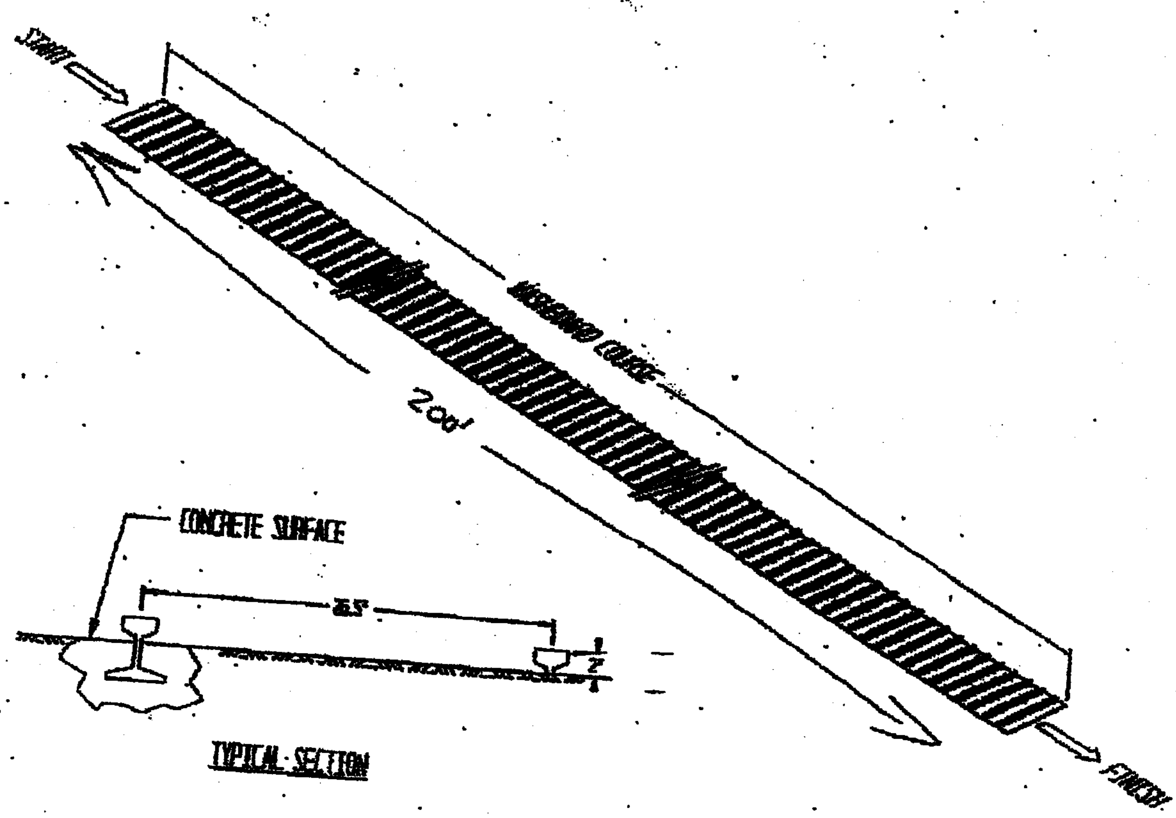


FIGURE 4

VIBRATION TESTING

Attachment 004

METHOD 514.4

VIBRATION

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I-1 PURPOSE. Vibration testing is performed to determine the resistance of equipment to vibrational stresses expected in its shipment and application environments.

I-2 ENVIRONMENTAL EFFECTS. Vibration can cause:

a. Wire chafing.

b. Loosening of fasteners.

c. Intermittent electrical contacts.

d. Touching and shorting of electrical parts.

e. Seal deformation.

f. Component fatigue.

g. Optical misalignment.

h. Cracking and rupturing.

i. Loosening of particles or parts that may become lodged in circuits or mechanisms.

j. Excessive electrical noise.

I-3 GUIDELINES FOR DETERMINING TEST PROCEDURES AND TEST CONDITIONS.

NOTE: The tailoring process as described in Section 4 of this document shall be used to determine the appropriate tests and test variables.

a. Application. This method is intended for all types of military equipment except as noted in the foreword to this standard.

b. Restrictions. None.

c. Sequence. Vibration testing may be performed anytime in the test program. The accumulated effects of vibration-induced stress may affect equipment performance under other environmental conditions, such as temperature, altitude, humidity, leakage or EMI/EMC. When it is desired to evaluate the cumulative environmental effects of vibration and other environments, a single test item should be exposed to all environmental conditions, with vibration testing generally performed first.

d. Test variation

(1) Test apparatus.

(2) Test item configuration.

(3) On/off state of test item.

(4) Vibration spectrum and intensity.

(5) Duration of exposure.

(6) Axes of exposure.

(7) Location of accelerometers.

I-3.1 Choice of test procedures. The choice of test procedure is governed by the vibration environments to be tested for. These environments should all be identified during the part of the tailoring process described in General Requirements, 4.2.2.

Table 514.4-I divides vibration environments into twelve categories--three transportation-induced and nine application-induced. Procedure I is used for testing an item to nine of these categories. Procedures II, III, and IV are each used for one of the three remaining categories.

TABLE 514.4-I Vibration environment categories. 1/

Division	Category	Description	Test Procedure	Test Conditions 2/
Transportation/ Cargo-Induced Vibration	1. Basic Transportation	Equipment carried as secured cargo. 3/	I	I-3.3.1
	2. Large Assembly Transport	Very large shelters, van, and trailer systems as an alternative to shaker testing.	II	I-3.3.2
	3. Loose Cargo Transport 4/	Equipment carried on ground vehicles as unrestrained cargo. 5/	III	I-3.3.3
Application-Induced Vibration	4. Propeller Aircraft and turbine engines	Equipment installed in propeller aircraft and on turbine engines manned and unmanned.	I	I-3.4.1
	5. Jet Aircraft/ Tactical Missiles	Equipment installed in jet aircraft, manned and unmanned, and installed in tactical missiles - free flight phase.	I	I-3.4.2
	6. Helicopter	Equipment installed in helicopters.	I	I-3.4.3
	7A. External Stores	Assembled stores externally carried on jet aircraft (including captive missile flight).	IV	I-3.4.4
	7B. External Stores	Equipment installed in stores externally carried on jet aircraft.	I	I-3.4.5
	7C. External Stores	Assembled stores externally carried on helicopters.	I	I-3.4.6
	8. Ground Mobile	Equipment installed in wheeled vehicles, trailers, and tracked vehicles.	I	I-3.4.7
	9. Marine	Equipment installed in ships or other naval watercraft.	I	I-3.4.8
	10. Minimum Integrity Test	a. All other. b. Vibration-isolated equipment.	I	I-3.4.9

1/ Also referred to as "equipment categories".
2/ The provisions of section I-4 apply to all vibration tests.
3/ Secured cargo. Cargo which is securely tied or blocked in all three axes with respect to the bed of the transport vehicle.
4/ Loose cargo. Cargo which is not tied, blocked, or restrained when placed on the bed of the transport vehicle.
5/ Restrained cargo Cargo which is blocked or tied in the two horizontal axes with respect to the bed of the transport vehicle.

I-3.4 Operational environments

I-3.4.1 Category 4 - Propeller aircraft and turbine engines.

I-3.4.1.1 Background information. Service vibration frequency spectra for equipment installed in propeller aircraft consist of a broadband background with superimposed narrow band spikes. The background spectrum results from various random sources (see I-3.4.2) with many periodic (not pure sinusoidal) components due to the rotating elements (engines, gearboxes, shafts, etc.) associated with turboprops. The spikes are produced by the passage of pressure fields rotating with the propeller blades. These occur in relatively narrow bands centered on the propeller passage frequency (number of blades multiplied by the propeller rpm) and harmonics.

The spectrum for equipment mounted directly on turbine engines is similar to the propeller aircraft spectrum except the primary spike frequency is the rotational speed of the rotor(s).

Most current propeller aircraft and many turbine engines are constant-speed machines. This means that rpm is held constant and power changes are made through fuel flow changes and variable-pitch blades, vanes, and propellers. These machines produce the fixed frequency spikes of figure 514.4-7. These spikes have an associated bandwidth because there is minor rpm drift and because the vibration is not pure sinusoidal (I-4.5).

There are indications that future turboprop or propfan engines will not be constant-speed machines. All reciprocating engines and many turbine engines are not constant-speed. Also modern turbofan engines usually have two and sometimes three mechanically independent rotors operating at different speeds. The spectra of figure 514.4-7 must be modified if used for these.

These vibration environments can be approximated in the laboratory by the source dwell test described in I-4.2.2. Many vibration problems in this type of environment are associated with the coincidence of equipment vibration modes and the excitation spikes. The notches between spikes are used in intelligent design as safe regions for critical vibration modes. Thus source dwell tests minimize the likelihood that equipment will be overstressed at non-representative conditions and that reasonable design provisions will not be subverted.

I-3.4.1.2 Test level. Whenever possible, flight vibration measurements should be used to develop vibration criteria for laboratory tests. In the absence of flight measurements, the test levels of table 514.4-II can be used with the spectra of figure 514.4-7. The turboprop levels are based on data from various C-130 and P-3 aircraft measurements and are fairly representative of the environments of these aircraft. The decline of spike acceleration spectral density with frequency is based on relatively recent data analyzed in a spectral density format. Engine levels are based on data measured on several current Air Force aircraft engines.

All equipment items protected from vibration by isolators should also pass the minimum integrity test requirements of I-3.4.9 with the test item hard-mounted to the fixture.

I-3.4.1.3 Test duration. Test durations should be developed from flight measurements or field data. If field data are not available for development of the test durations, tests should be conducted for one hour per axis at the test levels listed in table 514.4-II, modified according to the guidance in I-4.3, I-4.6 and I-4.7. These levels represent maximum actual operating conditions and are functional test levels.

I-3.4.2 Category 5 - Jet aircraft

I-3.4.2.1 Background information. The vibration environment for equipment installed in jet aircraft (except engine-mounted) stems from four principal mechanisms. These vibrations are random and, except where the elastic response of primary aircraft structure is the source, broadband. These sources are as follows:

a. Engine noise impinging on aircraft structures.

b. Turbulent aerodynamic flow along external aircraft structures.

c. Pressure pulse impingement due to repetitive firing of guns.

d. Airframe structural motions due to maneuvers, aerodynamic buffet, landing, taxi, etc.

The guidance provided in this section considers sources (a) and (b) above. Method 519 covers source (c). General airframe motions (d) cannot be adequately covered by general criteria. They are the result of responses of flexible structures to various transient events. Two examples of such responses are the rebound of wings and pylons when heavy stores are ejected, and the separated flow or shed vortex excitation of flight surfaces during sustained maneuvers. The vibration spectra are characteristic of the particular airframe involved and must be evaluated through measured data. Airframe structural motions are usually important for the outer regions of flexible structures (i.e. outer 1/2 of wings, empennage, pylons, etc). They are usually not important for fuselage-mounted equipment.

Jet-noise-induced vibration is usually dominant in vehicles which operate at lower dynamic pressures, i.e., limited to subsonic speeds at lower altitudes and transonic speeds at high altitudes. Aerodynamically induced vibration usually predominates in vehicles which operate at transonic speeds at lower altitudes or supersonic speeds at any altitude.

When equipment is used in more than one application, the vibration criteria should be enveloped and test criteria based on a worst-case composite. Only functional tests are performed for tactical missiles.

TABLE 514.4-II. Suggested functional test conditions for propeller aircraft and turbine engine equipment (see figure 514.4-7).

Equipment Location 2/, 3/	Vibration Level of L_1, at F_1, (g^2/Hz) 4/5/
In fuselage or wing forward of propeller	0.1
In fuselage or wing aft of propeller	0.3
In engine compartment or pylons	0.6
Equipment mounted directly on aircraft engines	1.0

1/ F_1 = fundamental excitation frequency; F_i = source frequency (i = 1-4).
$F_2 = 2F_1$, $F_3 = 3F_1$, $F_4 = 4F_1$

2/ When panels and racks are not available for equipment installed on vibration isolated panels or racks, or when the equipment is tested with isolators removed, use "fuselage or wing forward of propeller" category with levels reduced 4 dB.

3/ Increase test levels 6 dB for equipment mounted on fuselage or wing skin within one propeller blade radius of the plane of the propeller disc. For all other skin mounted equipment, increase levels by 3 dB.

4/ Bandwidth of vibration around each F_i will equal ±5% F_i for constant-speed excitation. When excitation is not constant-speed, bandwidth will encompass operating speeds for cruise and high power operation.

5/ F_1 = 68 Hz for most C-130 aircraft.

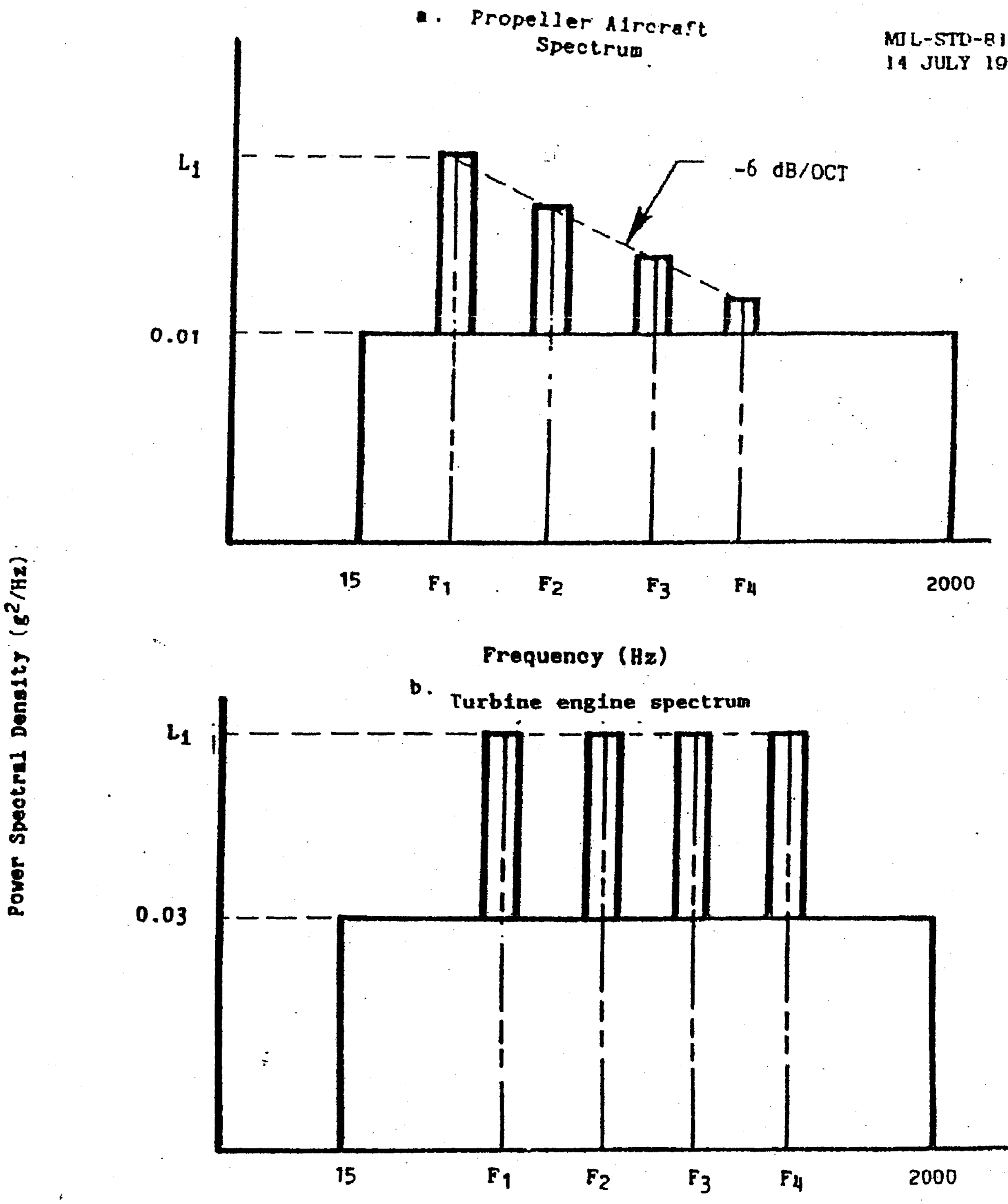


FIGURE 514.4-7. Suggested vibration spectra for propeller aircraft and equipment on turbine engines.

I-3.4.2.2 Test levels. In the absence of satisfactory measurements of field environments, functional test levels approximating jet-noise-induced and flow-induced vibration may be derived from table 514.4-III and figure 514.4-8. Aerodynamic and jet noise portions are not additive. Use worst case.

I-3.4.2.3 Test duration. Test durations should be developed from flight measurement or field data. If field data are not available for development of the test durations, then the test levels of table 514.4-III and guidance discussed in I-4.3, I-4.6, and I-4.7 apply. These levels represent maximum actual operating conditions and are functional test levels. The requirements of I-3.4.9 also apply.

I-3.4.3 Category 6 - Helicopter aircraft/installed.

I-3.4.3.1 Background information. Helicopter vibration is characterized by broadband random with superimposed strong vibration peaks, as depicted in figure 514.4-9. These peaks are generated by the rotating components in the helicopter, such as the main and tail rotors, engines and gear meshing. The operating speeds of these components under flight conditions are nearly constant, varying by only about five percent.

The relative levels of these peaks differ throughout the helicopter, depending on the proximity of the sources, geometry of the aircraft, and location of the test item. Thus, the need for measured data is especially acute. An obvious requirement for helicopter equipment design is to avoid a match or near match between an item's resonant frequencies and the excitation (source) frequencies at the installed location. The major peaks in the helicopter vibration spectrum are usually associated with the main rotor. However, each type of helicopter will have different sources within different areas of each aircraft. Since the vibration environment is dominated by these source frequency peaks, it is logical to use some of these frequencies for exposure in the laboratory test. Normally about four frequencies are chosen for the tests. For equipment mounted on engines, refer to I-3.4.1. For equipment exposed to gunfire vibration, refer to Method 519.

TABLE 514.4-III Broadband vibration test values for jet aircraft equipment.

Criteria

Aerodynamically induced vibration (figure 514.4-8) 1/

Functional test level 3/, 4/

$$W_o = K(q)^2$$

Jet engine noise induced vibration (figure 514.4-8) 1/

Functional test level 2/, 3/, 4/, 5/, 6/

$$W_o = (0.48 \cos^2 \Theta / R) \; [D_c \; (V_c/A)^3 + D_f \, (V_f/A)^3]$$

DEFINITIONS

K = 1.18×10^{-11} for cockpit panel equipment and equipment attached to structure in compartments adjacent to external surfaces that are smooth, free from discontinuities. ($K = 2.7 \times 10^{-8}$ if q is in lb/ft^2)

K = 6.11×10^{-11} for equipment attached to structure in compartments adjacent to or immediately aft of external surfaces having discontinuities (cavities, chines, blade antennas, speed brakes, etc.) and equipments in wings, pylons, stabilizers, and fuselage aft of trailing-edge wing root. ($K = 14 \times 10^{-8}$ if q is in lb/ft^2)

q = 57.46 N/m^2 (1200 lb/ft^2) or maximum aircraft q, whichever is less.

D_c = engine core exhaust diameter, meters (feet). (For engines without fans, use maximum exhaust diameter.)

D_f = engine fan exhaust diameter, meters (feet).

R = minimum distance between center of engine aft exhaust plane and the center of gravity of installed equipment, meters (feet).

V_c = engine core exhaust velocity, meters per sec (feet per sec). (For engines without fans, use maximum exhaust velocity without afterburner.)

V_f = engine fan exhaust velocity, meters per second (feet per sec).

Θ = angle between R line and engine exhaust axis, aft-vectored, degrees.

A = 1850 if engine exhaust velocities are in feet/sec.

A = 564 if engine exhaust velocities are in meters/sec.

TABLE 514.4-III. Broadband vibration test values for jet aircraft equipment. - Continued

NOTES

1/ Worst case aerodynamic or jet engine induced vibration should be identified and enveloped.

2/ If aircraft has more than one engine, W_o shall be the sum of the individually computed values for each engine.

3/ To account for the effect of equipment inertia on vibration levels, W_o may be multiplied by a mass loading factor M based on equipment weight in kilograms (Pounds). This does not apply to equipment which is on isolators.

$$M_f = 10^{(0.6 - Kg/60)};$$

$$M_f = 10^{(0.6 - 0.0075\ lb)}$$

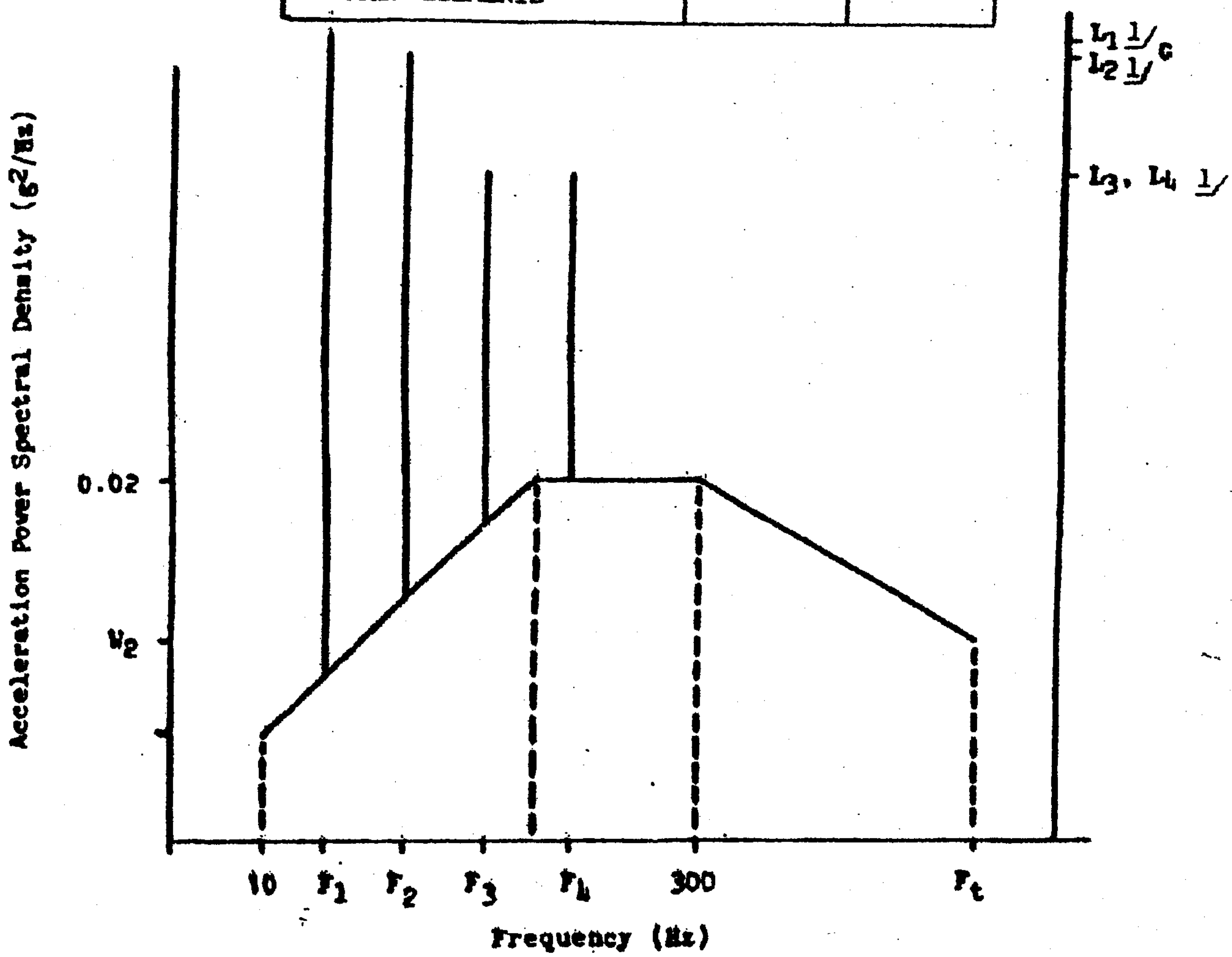
Values of M_f are restricted to the range 0.25 to 1.0.

4/ For $70^\circ < \Theta \leq 180^\circ$, use $\Theta = 70^\circ$ to compute W_o.

5/ For engines with afterburner, use W_o, which is four times larger than W_o computed using maximum V_c and V_f without afterburner.

6/ For instrument panel equipment, reduce the 0.04 G^2/Hz value of figure 514.4-8 by 3 and reduce the calculated value W_o by 6 dB for functional testing. Endurance is 0.04 g^2/Hz.

EQUIPMENT LOCATION	W_2	F_t
GENERAL	0.002	500
INSTRUMENT PANEL	0.002	500
EXTERNAL STORES	0.002	500
ON/NEAR DRIVE TRAIN ELEMENTS	0.02	2000



NOTE 1/ L_1, L_2, L_3 and L_4 G-Levels are determined from TABLE 514.4 - IV

FIGURE 514.4-9. Suggested vibration spectrum for equipment mounted on helicopters.

I-3.4.3.2 Test levels. For the reason stated above, the test levels for equipment installed in helicopters should be derived from field measurement. When measured data are not available, the test levels can be selected from figure 514.4-9 and table 514.4-IV. These levels are an attempt at enveloping potential worst-case environments. They do not represent environments under which vibration sensitive equipment should be expected to perform to specification. Costs for many devices are a strong function of the performance required in a particular vibration environment. Consequently, performance vibration levels should be tailored to particular applications and are not appropriate for a general standard.

For testing purposes, the aircraft can be divided into three zones, shown in figure 514.4-10. All equipment locations included in a vertical projection of the main rotor disc should use the source frequencies of the main rotor in determining the values of L_1, L_2, L_3, and L_4 (see table 514.4-IV). For equipment that will be located in the horizontal projection of the tail rotor disc, use the source frequencies of the tail rotor in determining the values of L_1, L_2, L_3, and L_4. The fundamental main and tail rotor source frequencies, F_1, for many helicopters are given in table 514.4-V. All equipment located on drive train components such as gear boxes and drive shafts should use the source frequencies of that drive train component (i.e., gear mesh frequencies, shaft rotational speeds). These drive train source frequencies must be determined from the drive train areas for the helicopter of interest.

I-3.4.3.3 Test duration. Test durations shall be derived from the field measurements and actual flight characteristics and durations.

I-3.4.4 Category 7A - Assembled external stores, jet aircraft. Assembled jet aircraft stores will encounter three distinct vibration environments: captive flight, buffet maneuver, and free flight.

I-3.4.4.1 Captive flight. Extensive measurement programs have shown that the vibration experienced by an externally carried store on a jet aircraft arises from three distinct sources:

a. Aerodynamic boundary layer turbulence.

b. Buffet maneuvers.

c. Aircraft-induced vibration.

In general, store vibration is primarily caused by broadband aerodynamic boundary layer turbulence and is relatively independent of the carrying aircraft and mounting location on the aircraft. Instead, vibratory excitation is mostly influenced by store shape, mounting configuration and dynamic pressure. This source of vibration is distributed along the entire surface of the store and is difficult to simulate by point input of vibration, such as from a vibration shaker, unless the store is relatively stiff. Therefore, an acoustic test (Method 515) is recommended for this environment.

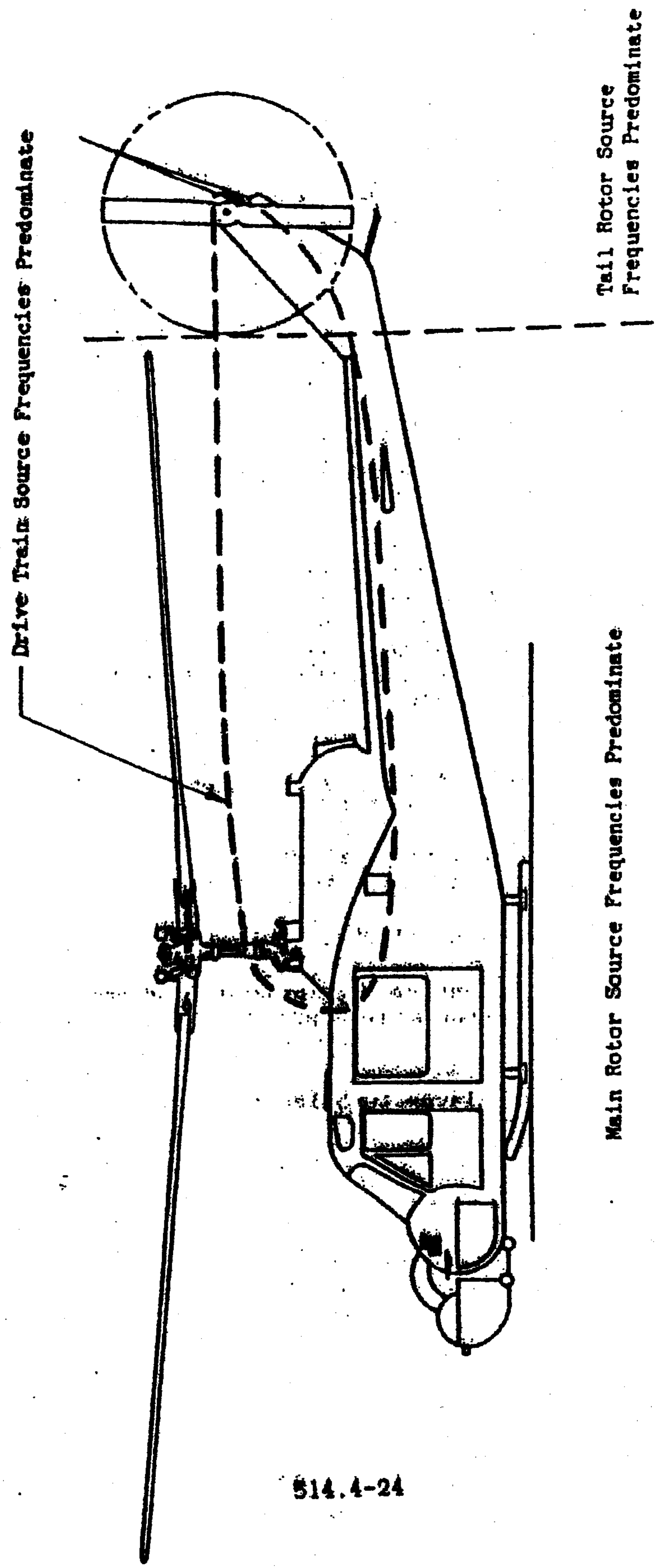


FIGURE 514.4-10. Zones for rotary wing aircraft.

TABLE 514.4-IV. Suggested functional test peak levels for equipment installed on helicopters.

Equipment Location	Source Frequency (Fx) Ranges	Peak Vibration Level (Lx) at Fx--G's
General (1)	5-25	0.1 Fx
	25-40	2.5
	40-50	6.5-0.1 Fx
	50-500	1.5
Instrument Panel (1)	5-25	0.07 Fx
	25-40	1.75
	40-50	4.55-0.07 Fx
	50-500	1.05
External Stores (1)	5-25	0.15 Fx
	25-40	3.75
	40-50	9.75-0.15 Fx
	50-500	2.25
On/Near Drive Systems Elements (2);	5-50	0.1 Fx
	50-2000	5+0.01 Fx

NOTES:

(1) Fx = Source Frequency of Interest = F_1, F_2, F_3, or F_4
F_1 = Fundamental Source Frequency
$F_2 = 2F_1$
$F_3 = 3F_1$
$F_4 = 4F_1$

Upon determining values of F_1, F_2, F_3, or F_4 (figure 514.4-9) select the appropriate source frequency range for each when determining peak vibration levels. The source frequency ranges are not presented in order of F_1=F_4.

(2) F_1, F_2, F_3, F_4 must be determined from drive train areas for the particular helicopter. NOTE (1) is then applicable.

TABLE 514.4-V. Fundamental source frequencies (F_1).

ROTARY WING AIRCRAFT	MAIN ROTOR F_1 (HZ) 1/	TAIL ROTOR F_1 (HZ) 2/
OH-58A	11.8	40
OH-58D	26.3	40
UH-60	17	20
CH-47D	11.3	3/
CH-47C	12.3	3/
AH-1	10.8	27.8
UH-1	10.8	27.8
AH-64	19.3	23.4
OH-6	31.9	51.3
CH-54	18.5	14.1
500MD	41	49
LYNX	21.7	32

1/ These frequencies are presented as the number of rotor blades times the rotor rotational speed.

2/ Rotor rotational speed.

3/ CH 47 has two main rotors and no tail rotor.